Thermal Stability and Degradation Behavior of Fibre Metal Mesh Laminate Composites by Thermo Gravimetric Analysis

M.Sakthivel 1, S.Vijayakumar 2
1 Assistant Professor, Dept of Mechanical Engineering, Adhiyamaan College of Engineering, Hozur-635109, Tamil Nadu, India. E-mail- metalsakthi@gmail.com
2 Assistant Professor, Dept of Mechanical Engineering, University College of Engineering, Kanchipuram-631552, Tamil Nadu, India. E-mail-svijayme@yahoo.co.in

Abstract— Fibre metal mesh laminate (FML) composites were prepared by the addition of woven glass fibre and stainless steel mesh with the epoxy resin. This paper deals with the influence of reinforcement on thermal stability and degradation of FML composites using Thermo Gravimetric Analysis (TGA). The thermo gravimetric technique was used to monitor the weight loss with the temperature. The FML composites were fabricated by five different combinations with varying weight % of woven glass fibre and epoxy resin. The Stainless Steel Mesh (SSM) maintained constant weight %. Thermo gravimetric test was conducted on all five composites in terms of changes in their thermal stability. The flame resistance and degradation behavior were also calculated using TGA. It was found that the thermal stability, flame resistance and degradation behavior of FML composites with higher fibre weight % was superior. The result shows the fibre fraction influencing the thermal stability and degradation behavior of the composites.

Keywords: FML, TGA, SSM, Thermal Stability, Degradation.

1. INTRODUCTION

Glass fibre reinforced polymer (GFRP) is being used logically as a part of a combination of basic applications by virtue of their mechanical properties and low weight, united with headways in manufacturing technology. However the utilization of this polymer is constrained in two routes, because of the allowable concentration of compounds. These compounds are characterized by stump thermal stability and the majority of them are thermally degraded at the temperature not higher than 220 to 250°C, which reduce their applicability to certain polymeric materials (Utracki et al., 2004). Recently, Fibre Metal Laminate (FML) composites became a subject of many studies and applications, polymeric materials and processing conditions on such FML properties as strength, elongation, elasticity, impact strength, thermal properties, flammability, resistance to thermal degradation and melt strength have been improved because fibre and metal used as reinforcement in polymer matrix (Tamer et al., 2011).

The FMLs has extensive variety of applications like sports utilities, airframe structures such as tennis rackets, bicycles, wings or airfoil parts and rotor blades. Composite laminates are highly customizable because fibre orientations can be adapted to any particular stress state. The resulting FMLs are finding applications in a number of new areas such as automobile engine cover assembly communication, satellites high density electronics, advanced aircraft requiring more efficient and lightweight thermal management materials (Vlot et al., 2001, and Wu et al., 1994). This is the evident that the thermal analysis of FMLs is required.

By concept of compelling thermal decomposition, the epoxy resin are new and astounding, which are similar or even better in ablative behavior than traditional phenolic systems (Hsu et al., 1982). Generally, with increased cross-linking density of epoxy matrix, the percentage of residue char will be higher and the efficiency is also improved. The residue char in high temperatures works as a binder and causes a better protection from the substrate degradation (Matzkanin et al., 1999). The general characteristic of a polymer is to protect a substrate material from heat damage (Pavli et al., 1969). According to the literature surveys, to obtain a high degree of insulating properties in a composite, the weight percentage of reinforcement should be in the range of 50 to 60%. Such systems, which consist of glass fibre with the weight percentage of epoxy resin, belong to the low-density ablators. Based on the literature surveys, the lower the density of the ablative composite protection will lead to higher thermal protection of the composite (Sigur et al., 1985).

Limited work has been reported on thermal stability and degradation of fibre metal laminate composites. So the present work focuses on the effect of fibre fraction in thermal stability and degradation of FML composites. The laminate composites fabricated using hand layup and vacuum bag molding method. The reinforcement material used is woven glass fibre and stainless steel mesh and epoxy resin is the matrix material. Thermal stability is analyzed using TGA. Using TGA results, the flame resistance and percentage degradation is calculated.
2. EXPERIMENTAL WORK

A. Materials

Epoxy purchased from Huntsman India Private Ltd., has excellent properties such as process ability as an ablator (Schwartz et al., 1967). This epoxy resin is a multi-functional epoxy that could produce higher strength network than the conventional epoxy resins. Ease of process ability and high thermal resistivity will cause such resin to be used as a binder (Turi et al., 1997).

B. Reinforcements

The E-glass woven fabric is used as a reinforcing agent because it exhibits superior strength-to-weight ratio and elevated fracture toughness than unidirectional composites (Teti R et al., 2002). The open metallic structure is penetrated by the epoxy resin, and consequently, the metallic structure is completely embedded in the epoxy matrix. Also, it enhances cracking behavior and energy absorption capability, the epoxy resin coating provides good corrosion resistance of the wire mesh. Because of the above reason the plain woven AISI 304 stainless steel wire mesh is used as an additional reinforcing agent in composites. The wire diameter of 112μm and mesh opening of 358μm. Before use, the mesh is cleaned in an alkaline soap bath for 30 minutes followed by a rinse in deionized water. To maintain same laminate thickness the glass weaved fabric layer is removed when the mesh is inserted into the stack. Both reinforcements were purchased from local resources.

C. Fabrication of Composites

Composite laminas are fabricated by using Hand Lay-Up method followed by Vacuum Bag Molding. The uncured lamina is prepared by using hand lay-up method. The Uncured lamina was placed in a mould and covered by the red film (has micro holes which allow excess resin passes through them when pressure is applied) and surface mat (used for absorbing excess resin).

The laminate is then used with 1.4 bar pressure for 2 hours and left in the mold for 24 hours for the pre-curing process. The final step is, placing the fabricated laminate in the hot air oven up to 3 hours at 100°C for the post-curing process. Same way layers are placed to prepare the 5 different composites combination. The weight percentages of various composites combination are shown in Table 1. The fabricated composites samples are shown in Figure 1.

![Fabricated Composites Sample](image)

**Figure 1** Fabricated Composites Sample

**Table 1** Weight Percentage of Different Composites Combination

<table>
<thead>
<tr>
<th>Sl no</th>
<th>Epoxy resin in wt %</th>
<th>Woven glass fibre in wt %</th>
<th>Stainless Steel mesh in wt %</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>60</td>
<td>10</td>
<td>C1</td>
</tr>
<tr>
<td>2</td>
<td>32.5</td>
<td>57.5</td>
<td>10</td>
<td>C2</td>
</tr>
<tr>
<td>3</td>
<td>35</td>
<td>55</td>
<td>10</td>
<td>C3</td>
</tr>
<tr>
<td>4</td>
<td>37.5</td>
<td>52.5</td>
<td>10</td>
<td>C4</td>
</tr>
<tr>
<td>5</td>
<td>40</td>
<td>50</td>
<td>10</td>
<td>C5</td>
</tr>
</tbody>
</table>

D. Specimen Preparation

The prepared slabs of the composite materials are taken from the mold and then samples were prepared from composite slabs for Thermo gravimetric tests. The test specimens are cut from laminate by using different tools. The sample weighs around 2 mg.

E. Thermo gravimetric analysis

TGA is a standout amongst the most supported systems for fast assessment in contrasting the thermal stability of various materials. The instrument used for this study is model SDT Q600 V8 builds ‘95 with a temperature build rate of 20°C/min over the range of room temperature to 800°C in nitrogen atmosphere. The
apparatus is computer controlled and calculations are done using pyrix software. The Thermo gravimetric test setup is shown in Figure 2.

![Figure 2 Thermo gravimetric test setup](image)

**F. Thermo gravimetric test**

The inert is set first (N₂) and oxidative (O₂) gas flow rates to provide the apt environments for the examination is set next. Place the test material in the specimen container and raise the furnace. Set the initial weight reading to 100% and then initiate the heating program. The gas environment is preselected for thermal decomposition. The test is conducted thrice for each combination to get reproducibility.

**3. RESULTS AND DISCUSSION**

Thermo Gravimetric analysis (TGA) is a method of thermal analysis used to measure the thermal stability of the composites, which observes the changes in physical and chemical properties of materials as a function of increasing temperature and time. TGA determines the weight loss or gain by decomposing the composites. The typical TGA curve obtained from thermo gravimetric test was shown in Figure 3. The thermal properties of the woven glass fibre /stainless steel mesh filled epoxy composites are measured by TGA at a heating rate of 20°C/min under nitrogen atmosphere. The TG and DTG curves for FMML composites are shown in Figure 4 and 5. It shows that the degradation of composites occurs in two stages. The weight loss of epoxy resin or other impurities occurred at the first stage between 33°C and 338°C. The weight loss of cured epoxy resin occurred at the second stage between 338°C to 419°C. It is found that the weight loss of the composite C5 (40 wt% epoxy resin) is higher than the weight loss of the other composite combinations. It may be due to the decrease in cross-linking density of epoxy, due to the weight percentage of epoxy resin.

![Figure 3 Typical TGA curve](image)
Figure 4 TG curves of FMML composites

![TG curves of FMML composites](image)

Figure 5 DTG curves of FMML composites

![DTG curves of FMML composites](image)

All the samples illustrate good thermal stability up to 381°C. All the composite samples indicated two-stage decomposition at 338°C and 419°C which are attributed to the decomposition of epoxy resin. Further, based on char yield percentage, Limiting Oxygen Index (LOI) values are determined and appeared in Table 2. The TGA data confirms that composite C1 has higher thermal stability over the other composite. From the residue content, the LOI value is calculated using Krevelen’s relation LOI = 17.5 + 0.4 σ (Van Krevelen et al., 1975). If the value of LOI is greater than 26, it has good flame resistance. Among the five composite samples, Composite C1 is found to have its LOI value closest to 45. Therefore, it is evident that composite C1 has fine flame resistance. LOI values of FMML composites were shown in Table 2.

**Table 2** LOI Values of FMML Composites

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Limiting Oxygen Index (LOI) values</th>
<th>Char yield σ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>45</td>
<td>70.12</td>
</tr>
<tr>
<td>C2</td>
<td>43</td>
<td>65.54</td>
</tr>
<tr>
<td>C3</td>
<td>42</td>
<td>63.64</td>
</tr>
<tr>
<td>C4</td>
<td>40</td>
<td>58.57</td>
</tr>
<tr>
<td>C5</td>
<td>39</td>
<td>56.3</td>
</tr>
</tbody>
</table>

Figure 4 and 5 demonstrate the degradation curves of FMML composites with a different weight fraction of woven glass fibre and epoxy. From the which, it was observed that composites with higher fibre fraction indicated higher thermal stability. The degradation behavior of a given composite is hence all that much subject to the extent of its constituent materials. The degradation pattern represents the composition of the composite as a whole. For instance, when glass fibre and stainless steel mesh was subjected to thermal
degradation, the residue weight percentage at 785°C was found to be 70.12% to 56.3%. Table 3 shows the percentage residue and degradation composites. The percentage degradation stumpy when the resin weight % was low. Once resin % weight increases the percentage degradation also increases. From these outcomes, it was observed that the fibre fraction influences the degradation behavior of the composites.

\[ D = (100 - X) \quad \text{(1)} \]

Where D is the percentage degradation, X is the residue weight percentage of the composite obtained at 785°C from TGA data.

### Table 3 Percentage Degradation of FMML Composites

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Percentage degradation</th>
<th>Residue in wt %</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>29.88</td>
<td>70.12</td>
</tr>
<tr>
<td>C2</td>
<td>34.46</td>
<td>65.54</td>
</tr>
<tr>
<td>C3</td>
<td>36.36</td>
<td>63.64</td>
</tr>
<tr>
<td>C4</td>
<td>41.43</td>
<td>58.57</td>
</tr>
<tr>
<td>C5</td>
<td>43.7</td>
<td>56.3</td>
</tr>
</tbody>
</table>

### 4. CONCLUSIONS

The thermal behaviors of FMML Composites were studied using TGA. From the results, it was observed that the composites C1(Woven glass fibre weight % 60, Stainless steel mesh weight % 10 and Epoxy weight % 30) have better thermal stability(381°C) and flame resistance(AL value was 45) than other combinations. The reason was fibre fraction of the composites.

The degradation behavior of composites C1 was minimum (29.88%) and higher for Composite C5 (43.7%) due to the weight fraction of woven glass fibre and stainless steel mesh.

The vicinity of woven glass fibre and stainless steel mesh caused polymer thermal stability enhancement. The woven glass fibre and stainless steel mesh exhibit more intensive char formation on the surface of the sample exposed to heat. It protects the bulk of sample from heat and diminishes the rate of mass loss during thermal decomposition of FMML composites. This composite was recommended for lightweight thermal management materials.

### References


Tamer Sinmaçelik,a,b, Egemen Avcu a, Mustafa Özgür Bora, Onur Çoban, A review: Fibre metal laminates, background, bonding types and applied test methods, Materials and Design, Vol.32, pp.3671-3685,2011.


